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Rain intrusion rates at façade details – a summary of results from four laboratory studies

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Abstract

More knowledge and realistic data on inward leakage is needed not only to better understand and confirm rain resistance of different facades, but also to carry out reliable theoretical moisture risk assessments of façade details in external walls. This article is an attempt to highlight amounts of expected leakage based on four laboratory studies. The results show that under heavy driving rain conditions, there may be continuous point leakage of significant volumes of water (0,01-0,05 l/min) in small invisible deficiencies, and corresponds to up to 2% of the applied water load. The leakage rate also depends, more or less, on the size, position and geometry of the deficiency, cumulative runoff rates, size of projecting details and surface properties.

Keywords: Driving rain; water lekage, rain intrusion, wall, window, building envelope, risk assessment, EN 12865

1. Introduction

One of the intended functions of the exterior walls is to separate and protect the indoor from the outdoor climate to provide an energy efficient building with good indoor environment (thermal comfort, shading from sun and rain

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etc.). However, water can leak into outer walls and façades (1-3) to a greater or lesser degree, even in pressure-equalized façades (3, 4).

Further, the risk of rain intrusion is greater in the presence of façade details than in an unimpaired wall, since inward leakage often occurs in correspondence to the joints around façade details. Joints around window-wall interfaces are one of the most common façade details, and windows often make up a relatively large proportion of the façade area. For this reason, although the façade material itself is impervious to rain, the wall itself may still be damaged due to leaks around façade details (5). Research in this area has been performed in order to quantify and understand the amount of leakage but more research is needed (6, 7) and to design and assess new and existing solutions, in a reliable manner (8).

The purpose of this summary is to give a picture of expected rain intrusion rate at façade details during driving rain conditions.

2. Four laboratory studies

Laboratory measurements allow us to study how façades behave in response to specific different loads, to reproduce trials, assure resistance to driving rain and quantify leakage in a controlled manner. These types of studies are not easy to perform in the field, as it is highly time-consuming and requires a lot of resources. Given the need for more knowledge of façade rain resistance and inward leakage rates, brief results from 4 studies are summarized here. The first three studies are fully or partly published before, the last one is not: Hundreds of commercial tests performed on commission from customers (9); 29 window-wall interfaces and comparison between well and not well designed/performed joints around windows (10); different façade details with small visible and invisible deficiencies (11); slits with different geometry and size.

2.1. Test procedures

The experiment was carried out partly using the standardised test method of EN 12865 "Determination of the resistance of external wall systems to driving rain under pulsating air pressure", but was extended to include additional load combinations and repetitions (12). Simulation of driving rain was obtained by using specified water spray nozzles (1.5 l/min-m^2 and run-off of 1.2 l/min-m) and dynamic pressure loading with compressed air at successive pressure steps, such as 0 Pa, 0–75 Pa, 0–150 Pa, 0–300 Pa, 0–450 Pa and 0–600 Pa. In some of these experiments, the rain load was also reduced to represent lower driving rain intensity.

Under each façade detail, collection funnels were fitted against the rear of the façade. Each funnel emptied into a glass bowl or plastic container to collect the water and weigh it. However, the actual leakage rate was not measured in the study of hundred commercial tests. Instead the leakage rate was estimated and classified to a five-point scale.

2.2. Tested walls

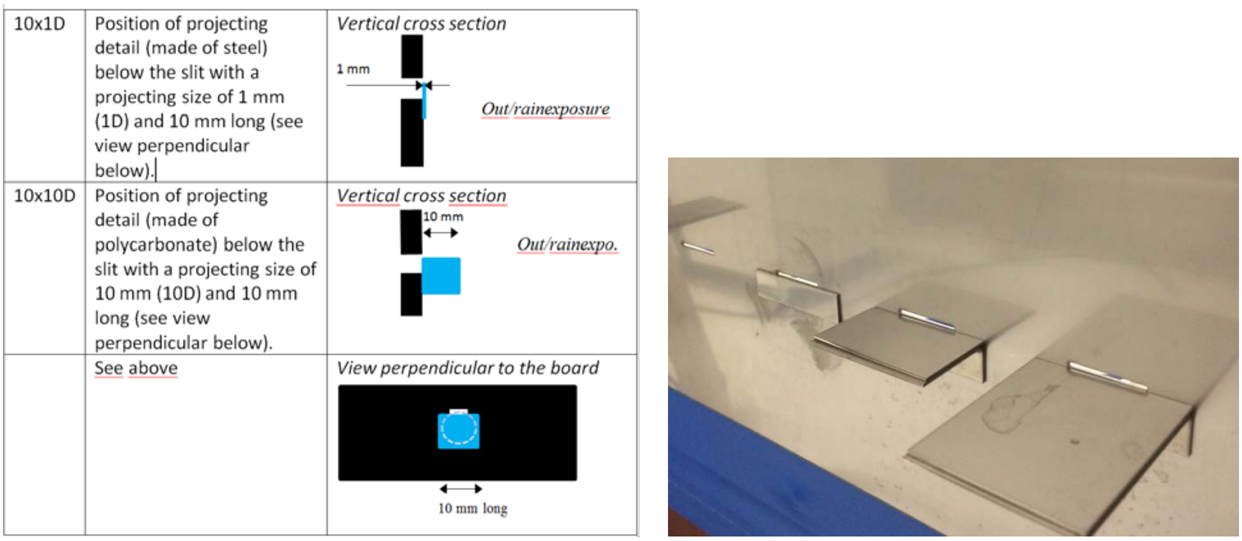
Various types of commercial façade systems and weather barrier systems (hundred commercial tests) were tested in full-scale wall (3 x 3 m) with a set of predesigned common façade details (9). The tested systems were for example: ventilated façades with façade layer of render on fiber cement board, fiber cement board, composite board and wood panel. Furthermore, sandwich element of metal sheets or concrete with cellular plastic insulation and ETICS (External Thermal Insulation Composite Systems) as well as ETICS with a drainage possibility on the outside between the second line of defense and substrate were tested. The test walls were mainly mounted by the façade supplier themselves.

In the study of 29 window-wall interfaces, windows were mounted in four test walls (3 x 3 m) with three different façades or wall constructions, such as: one with ventilated composite board as façade, one with concrete façade of sandwich element of concrete with cellular plastic within and two with ETICS with a drainage possibility on the outside between the second line of defense and substrate (10). Actually, some of the window-wall interfaces had intentionally not well performed joints for the reason to compare it with well performed joints (by façade supplier).

Table 1. Description of the deficiency at the details in terms of deficiency or aperture dimensions, plus remarks as to whether the deficiency are concealed, invisible or visible.

Detail	Deficiency dimension (mm)	Comments
1. Window-wall	(1,5x1,5) + (0,2x9) + (0,1x50)	Concealed position
2. Window-wall	2 x 2	Concealed position
3. Circular duct	0,9 x 35	Visible
4. Rectangular duct	2 x 30	Visible
5. Metal flashing	0,1 x 35	Not visible
6. Metal flashing	Not measurable	Not visible
7. Underneath flashing	0,3 x 120	Concealed, only exposed to water splash from below

The study with different façade details (11) consisted of small visible and invisible deficiencies. The façade (3 x 3 m) consisted of an impregnated (water proof and water- repellent) plaster based board. The deficiencies was selected and designed based on findings from investigations in both laboratory and field, see Table 1.



(a) (b)

Fig. 1. (a) Description of projecting details for fiber cement board. (b) Photo of stainless steel plate and slits with projecting details seen from the left (1x20), (1x20,40x1D), (1x20,40x25D) and (1x20,40x50D).

In the study with horizontal slits, the slits were rectangular with different sizes (0,3 to 2 mm thick and 3 to 20 mm long) in a vertical mounted fiber cement board (6 mm) and stainless steel plate (1 mm) with a size of 1200 mm x 1200 mm. Additionally, some projecting details were mounted on the outside and below the slits (to simulate penetrations, metal flashings etc.) for fiber cement board, see Fig. 1a, and for stainless steel plate, see Fig. 1b. The hole in the fiber cement board, behind the slits, was 6 mm in diameter for 3 and 4 mm slits length and 8 mm for longer slits. The slits in the fiber cement board were created at the top edge of the holes with a file. The slits in the stainless steel plate were created by abrasive waterjet cutting.

3. Results and comments

Based on 110 tested façade designs more than 90% failed and nearly 50% of all details failed (9). Failed means that water leaked through the rain-exposed surface into air cavity, drainage gap, and thermal insulation as plaster substrate or load bearing structure. Overall, one of the details which failed most was window-wall interfaces “fail ratio” of 60-80%. To summarize, three quarters of all test facades had significant rain intrusion, continuously dripping and low flow, which are defined as being in a range of approximately 0.01–0.05 l/min, see Table 2. Additionally, very few details had modest leakage flow and none of them had heavy leakage flow.

Table 2. Results of estimated rain intrusion rate (not measured) of walls that failed/leaked. This result includes only the defect that leaked most in each wall.

Estimated rain intrusion rate	Estimated rate (l/min)	Walls that leaked (%)
One or few drops	≤0,0001	20
Continuously dripping	0,001-0,01	53
Low flow	0,02-0,05	25
Modest flow	0,06-0,1	2
Heavy flow	≥0,2	0

Out of 29 tested window-wall interfaces a fail ratio of 60% was conducted (10). The largest leakage flow was approximately 0,03 l/min. The second and third largest flows were between 0,008 and 0,006 l/min. Water leakage began already at 0 Pa, even without any wind loads. Further, in many cases the water leakage was not proportional to the erection performance - did not show any obvious difference regarding rain resistance and amounts of leakage.

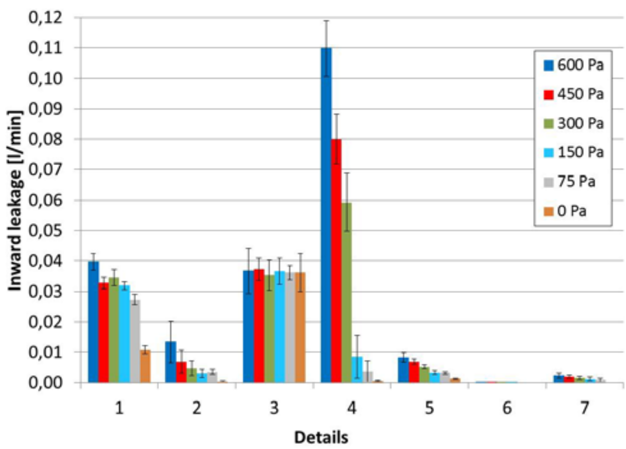


Fig 2. The bars show inward leakage (mean value of 3-7 repetitions) for the deficiency in the relevant detail for six pressure steps/wind pressure with pulsation. The applied water load was rain at 2.9 l/min-m above the deficiency. The standard deviation is also shown.

In the third study (11) with different façade details, the deficiency in detail 1 resulted in inward leakage of between 0.027 and 0.04 l/min at a wind pressure of 75 to 600 Pa, see Fig. 2. At a wind pressure of 0 Pa, inward leakage was already 0.011 l/min. At detail 3 resulted in inward leakage of approximately 0.036 l/min regardless of the amount of wind pressure. The driving force behind inward leakage was therefore not a difference in pressure, and similar experiences is previously pointed out by Lacasse (13) and Straube (4).

The deficiency in detail 4 resulted in great inward leakage of between 0.06 and 0.11 l/min at a wind pressure of 300 to 600 Pa. The deficiency in detail 5 resulted in inward leakage of between 0.001 and 0.008 l/min, with the leakage increasing in proportion to increases in wind pressure. Bearing in mind, this flaw was small and invisible.

These amounts of leakage, at detail 1 and 3, concentrated to point leakage, in these studies corresponds approximately to up to 1,1 % of the applied water load (2,9 l/min,m). Furthermore, approximately 2% inward leakage of the applied water load was obtained when the water load was halved (1,22 l/min,m) and is a more frequent exposure in reality (13). For example, in a medium-rise building the cumulative runoff rates during driving rain correspond approximately to the applied water load in this study.

Even the smaller slits (0,3 x 3 mm and 0,4 x 4 mm), see Fig. 3a, in the last study, resulted in inward leakage of around 0.015 l/min almost regardless of the amount of wind pressure up to 150 Pa. This implies that large volumes of water can penetrate without wind pressure if the façade is exposed to heavy rain loads. The driving force behind inward leakage was therefore not due to a difference in air pressure. The reason why smaller and bigger slits got almost the same leakage amounts has not yet been addressed. These amounts of leakage, concentrated to point leakage, in these study corresponds approximately to up to 0,7 % of the applied water load (2,9 l/min,m).

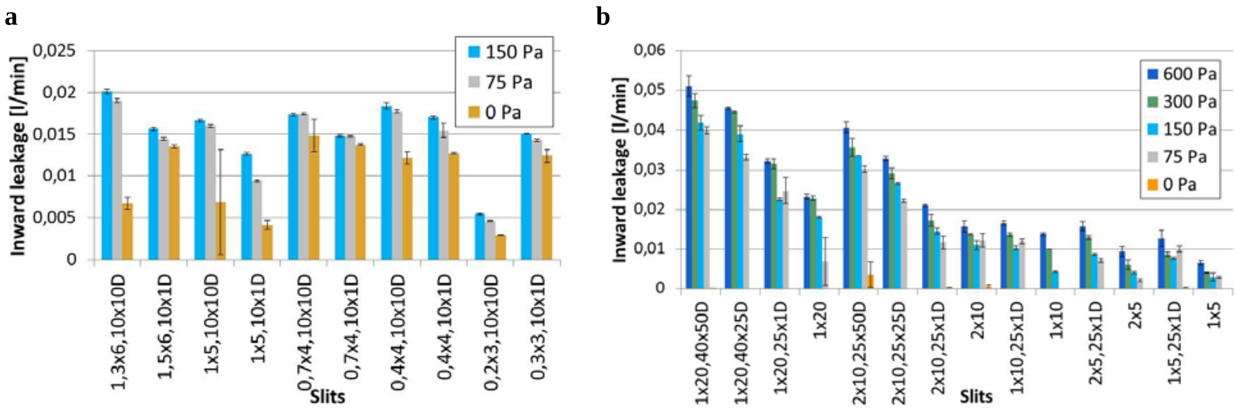


Fig. 3. The bars show inward leakage (mean value of 3 repetitions) for the deficiency in the relevant slits for three or five pressure steps/wind pressure with pulsation. (a) The applied water load was rain at 2.9 l/min-m above the deficiency on fiber cement board; (b) The applied water load was rain at 2.9 l/min-m above the deficiency on stainless steel plate. The standard deviation is also shown.

The slits in the stainless steel plate resulted in inward leakage of between 0.01 and 0.05 l/min, with the leakage increasing more or less in proportion to increases in slits length, see Fig. 3b. Without wind pressure (0 Pa), inward leakage was small or nothing at all in most slits. It is also clear that the significance of the extent of the difference in air pressure at pressures above 75 Pa was comparatively limited but noticeable. These amounts of leakage, concentrated to point leakage, in these study corresponds approximately to up to 1,7 % of the applied water load (2,9 l/min,m). A recent study (14) of this topic shows a point leakage amount of up to approximately 1,5 % of real life water load of experimental walls.

4. Conclusions

Based on these four studies, the results shows that under heavy driving rain conditions, point leakage of significant volumes of water in a magnitude of 0,01-0,05 l/min in small invisible deficiencies. The leakage rates also depend, more or less, on the size, position and geometry of the hole/deficiency, cumulative runoff rates, surface properties and the size of the projecting details etc. The leakage amount corresponds approximately to up to 2% of the applied water load (the total water volume (l/min,m) that runs along the deficiencies).

The second study (29 window-wall interfaces) - with best possible installation, compared to man-made flaws - did not show any obvious difference regarding rain resistance and amounts of leakage, despite the difference in mounting performance.

Based on these results, we can confirm that commercial well performed and sealed joints around the windows in façades are, despite all, usually not rain resistant, which should be considered, for example in risk assessments. Since it concerns point leakage, two-or three dimensional simulations are required in order to be able to consider this in a realistic way. Exactly how the spread of the leakage in the wall appears, needs to be known or investigated, alternatively that the worst case scenario (the whole leakage is placed concentrated and in the most critical point) is applied. The leakage amount should particularly be considered if the second line of defense is not verified with respect to rain resistance and if there is a risk of water accumulation (if drainage is no verified) within the wall.

Acknowledgements

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